Local virial relation and velocity anisotropy in self-gravitating system

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Abstract.

We investigate the merging process in N-body self-gravitating system from the viewpoints of the local virial relation which is the relation between the local kinetic energy and the local potential. We compare both the density profile and the phase space density profile in cosmological simulations with the critical solutions of collisionless static state satisfying the local virial (LV) relation. We got the results that the critical solution can explain the characteristic density profile with the appropriate value of anisotropy parameter $\beta \sim 0.5$. It can also explain the power law of the phase space density profile in the outer part of a bound state. However, it fails in explaining the central low temperature part which is connected to the scale invariant phase space density. It can be well fitted to the critical solution with the higher value of $\beta \sim 0.75$. These results indicate that the LV relation is not compatible with the scale invariant phase space density in cosmological simulation.

1. Introduction

It is well known that astronomical objects are formed through the merging process of small clusters under the homogeneous expanding background. It is also well known that the bound state after the merging process in cosmological simulations takes rather universal form of a cuspy density profile, $\rho \sim r^{-\gamma}$ in the inner part, where $\gamma \approx 1$ [1]. There is another universal character for the virialized state following merging process, that is, the scaling law of a phase space density, $\rho/\sigma^3 \sim r^{-\alpha}$ where $\alpha \approx 1.9$ [2]. Several models are proposed to explain both of these characters. For example, W.Dehnen and D.E.McLaughlin show that the critical solution for the static Vlasov equations under the scale invariant phase space density is compatible with NFW density profile [3].

In our previous paper, we examined cold collapse simulations and got the result that the bound state after a collapse has several remarkable characters [4, 5, 6]. The LV relation is one of such characters. The Plummer model which is the analytical solution for polytrope with index n=5 satisfies this condition. The Plummer model has the property that the velocity dispersion is isotropic. However, the velocity dispersion is not always isotropic for the quasi-equilibrium state and is characterized with non-zero anisotropy parameter $\beta\,(r)$. The analytical solution exists even for the non-zero constant value of β under the condition of the LV relation [8]. We showed by combining these analytical solutions that the bound state after the cold collapse can

be described quite well by the solution with the LV condition [6, 7]. We also showed that the analytical solution in [8] can be characterized as a critical solution connecting two fixed points as is shown in [3]. We got the results that the LV relation is rather special in that the critical solution connecting the two fixed points exist only in the case with the virial ratio $b = 1$ among the models with general constant b models. Here we investigate whether or not the model with the LV relation can explain several characters of the cosmological simulations by using the constant β critical solutions.

2. Analysis and conclusion

Here we examined the character of the bound state for a typical cosmological simulation. The numerical data of the cosmological simulation was provided to us by H.Kase at Tokyo University. We got the result that the LV relation is satisfied quite well in the cosmological simulation except for the inner region of a bound state. We examined the character of the bound state derived from the cosmological simulation with the constant β critical solutions under the LV relation. The difference of the results between cold collapse and cosmological simulations are remarkable. In cold collapse simulations from a homogeneous sphere, the central part of the bound state becomes flat, which can be described by the β=0 critical solution, while the outer part can be described by connecting the inner Plummer model with outer $\beta > 0$ critical solution [6, 7]. In the cosmological simulation, on the other hand, the inner part is peculiar, i.e., the temperature $k_B T/m (= \sigma^2/3)$ falls down in the central part of the bound state (Fig.1). In this region, the LV relation is not attained, while the phase space density takes a scaling property quite well. These results indicate that there are two types of initial conditions ,i.e., the one settling down to the bound state with the LV relation and the other settling to the scale invariant phase-space density.

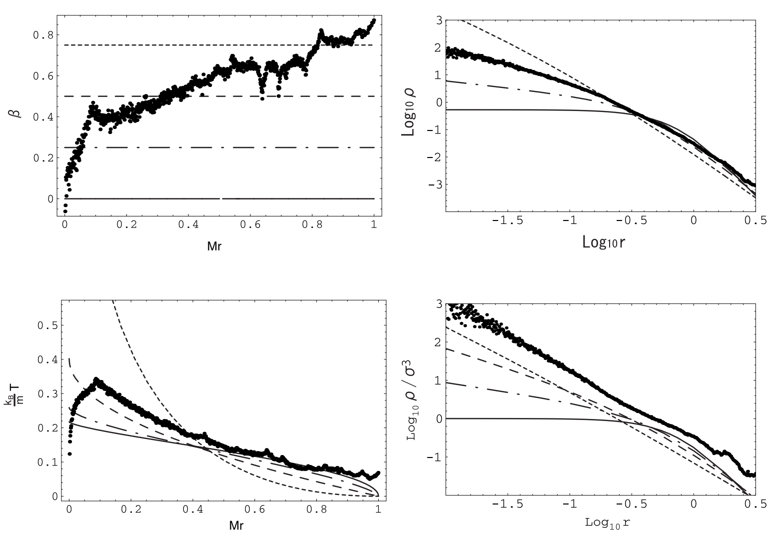

Figure 1. The behaviour of several physical quantities for a cosmological simulation. In the left figures, the horizontal axis represents the cumulative mass normalized with the total mass of the bound state. Each line represents the critical solution with $\beta = 0$(solid line), 0.25(dot-dashed line), 0.5(dashed line), 0.75(dotted line), respectively.The density fits well to $\beta = 0.5$ critical solution, while phase space density fits rather to $\beta = 0.75$ critical solution.

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